The platypus *Ornithorhynchus anatinus* in headwater streams, and effects of pre-Code forest clearfelling, in the South Esk River catchment, Tasmania, Australia

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ABSTRACT

This study examined the occurrence, relative abundance and condition of platypuses in the upper catchment of the South Esk River, in north-east Tasmania, Australia, and the impact of past forestry activities on the occurrence of platypuses in first order headwater streams. The main trapping sites were in twenty first order streams, eight second-fourth order headwater streams and one fifth order stream reach. Additional trapping was also undertaken in the South Esk River and farm dams. Sites were trapped during late spring/mid summer and early autumn. A total of 78 individuals were caught in the study area. Platypuses were caught at all sites trapped in the second-fourth order and fifth order stream reaches and in nine of the twenty first order streams. Catch success was greatest in the fifth order stream reach and lowest in the first order streams. There was a trend toward a higher proportion of juvenile/subadult males in the lower order stream sites. For the higher stream orders, a higher proportion of individuals was caught during the summer, however for the first order streams, a higher proportion was caught during the autumn trapping period.

Information collected on the body mass, body length and condition of individuals indicated smaller individuals with a higher tail fat index in the lower order streams.

There was a trend toward a lower occurrence of platypuses in the first order streams, which had been disturbed 15 years previously by forestry operations compared to first order streams with relatively undisturbed catchments. Differences in occurrence of platypuses were related to differences in the 'in-stream' and riparian characteristics of disturbed streams compared to undisturbed streams. Headwater streams form a large proportion of a river system. Although they provide more marginal habitat for the platypus than larger river reaches, their disturbance may be an important land management issue in the conservation of this species, particularly in river catchments where the species is impacted by other environmental changes or disease.

Key words: platypus; distribution; first order streams; headwater streams; stream management; forestry; habitat quality; catchment management; conservation.

Introduction

The platypus *Ornithorhynchus anatinus* is known to occur in 79% of the river systems in Tasmania (Grant 1992; Connolly and Obendorf 1998) and is widespread and common throughout the State (Rounsevell *et al.* 1991). Despite its widespread occurrence and high public profile, little detailed research has been carried out on the ecology of the species in this State until recently. In particular there is a lack of information on the distribution, population sizes and condition of platypus within Tasmanian river catchments. Such information is important in assessing any changes in the occurrence of platypus in Tasmania caused by disease or habitat disturbance.

Studies of platypus distribution within river catchments have been undertaken on mainland Australia (e.g. Turnbull 1998; Rohweder and Baverstock 1999). These studies found that platypuses occurred in water bodies throughout the catchments but were less common in the upper parts of catchments. Rohweder and Baverstock (1999) attributed the absence of platypus from some upstream sites in the Richmond river catchment to a range of factors including seasonal stream flow, pool size, and the availability of burrow sites. Optimal habitat for the platypus identified by several habitat studies is generally described as permanent water bodies with consolidated earth banks, overhanging riparian vegetation and pools with relatively shallow water (Ellem *et al.* 1998, Grant 2004, Serena *et al.* 1998, 2001). Such habitat is predominantly found in the middle and lower parts of river catchments, with the majority of headwaters dominated by small, often ephemeral streams.

Platypuses are known to occupy quite degraded stream systems (Grant and Bishop 1998; Grant and

Temple-Smith 2003). Impacts of forestry activities on Australasian streams include changes in stream hydrology (Vertessey 1999), alteration of stream bank stability and sediment retention (Davies and Nelson 1994; Bunce *et al*. 2001), reduction in shading and increased water temperatures (Lake and Marchant 1990; Webster *et al.* 1992), modification of organic debris and channel morphology (Davies and Nelson 1994; Bunce *et al.* 2001), changes to stream sediment particle size distributions (Scrivener 1987; Davies and Nelson 1993; Bunce *et al.* 2001) and changes in aquatic macroinvertebrate and fish assemblages and populations (Davies and Nelson 1994; Growns and Davis 1994). Despite these known changes to habitat, platypuses have been recorded in streams downstream from areas subject to logging (Grant 1991; Turnbull 1998). However, there have been no published studies that have directly assessed the effects of forestry activities on platypus population numbers.

This study aimed to determine the occurrence of platypuses in streams throughout the upper catchment of the South Esk River in northeast Tasmania. In particular, we aimed to determine the characteristics of first order headwater streams (*sensu* Strahler 1975) used by platypuses and to assess the use of first order streams that had been disturbed 15 years previously by clearfelling. The work was part of a broader collaborative research program investigating the impacts of past forestry activities on the geomorphology, hydrology and instream biota of headwater streams (Bunce *et al* 2001; Davies *et al*. 2005a and b).

Methods

Study Area

The study was carried out in stream channels of the upper catchment of the South Esk River, draining and adjacent to the forested eastern slopes of Ben Nevis in North-East Tasmania (Davies *et al*. 2005a; Figure 1). The elevation of the study area ranged from 380 to 950 m. Annual total rainfall was around 1086 mm, with a highest monthly precipitation of around 266 mm during the winter (June-August) months (Bureau of Meteorology; data from 1978-1999; see also Davies *et al*., 2005a).

The area is underlain predominantly by biotite granite/adamellite and granodiorite (Department of Mines 1993). The vegetation varies from dry sclerophyll eucalypt forest, dominated by *Eucalyptus delegatensis* with a shrubby understorey on more insolated sites, to wet sclerophyll and mixed eucalypt forest, dominated by *E. delegatensis* and *E. dalrympleana* on more sheltered aspects. The riparian zone of the headwater streams supports vegetation that is at least partly distinctive from the surrounding slope vegetation in a 10 - 20 m band on either side of the stream channels. The upper catchment may also contain small shrubby wetlands. Riparian vegetation is characterised by rainforest (dominated by myrtle *Nothofagus cunninghamii,* and sassafras *Atherosperma moschatum*) and swamp forest (dominated by woolly tea-tree *Leptospermum lanigerum*). Slopes fall mostly between 0 and 11° (Davies *et al*. 2005a).

The streams in the area support a range of aquatic and semi-aquatic macrophyte, macro-invertebrate and vertebrate communities (Davies *et al*. 2005b). All upper catchment first order streams are fishless. Brown trout *Salmo trutta* and shortfin eel *Anguilla australis* occur in most drainages downstream.

Most of the study area has been periodically selectively logged since European settlement. In 1985 (i.e., 15 years prior to this study) part of the study area was clear-felled using heavy machinery resulting in significant disturbance to the small headwater streams and their catchments (Bunce *et al*. 2001). These forestry operations were conducted prior to the development of the Tasmanian Forest Practices Code (Forest Practices Board 2000). Hence, they were not limited by current Code provisions that aim to limit the direct effects of clearfelling, ie. crossing of streams by heavy machinery, dragging of trees across first order streams, and felling of trees into streams and related disturbance to riparian zones. Figure 2 illustrates the extent of disturbance by forestry operations in several headwater streams sampled in this study.

Stream Selection

Twenty headwater, first order streams (0 - 40 cm deep, 0 - 100 cm wide), eight second, third or fourth order streams (20 – 120 cm deep, 80 - 300 cm wide) and one fifth order reach of the South Esk River (30 – 2000 cm deep, 500 - 1000 cm wide), close to the small community of Upper Esk, were selected as the main sampling sites for sampling in 2000/01 (Figure 1).

Ten of the first order streams (mean catchment area, 42 ha, range 6 - 137 ha) had relatively undisturbed native forest catchments (Figure 1 and 2) and 10 (mean catchment area, 45 ha, range 15 – 85 ha) had native forest catchments that were regenerating following intensive clearfell, burn and sow forestry operations conducted in 1985 (Figures 1 and 2). This sample of first order streams included several selected for a concurrent study on the impact of the 1985 forestry operations on their riparian and aquatic flora, geomorphology, sediments and macroinvertebrate fauna (Bunce *et al*., 2001; Davies *et al*. 2005a and b).

In addition to the main sampling sites illustrated in Figure 1, three additional reaches on the South Esk River (5^{th} and 6^{th} order) and three farm dams (200 m long, 50 m wide, 2 m deep) at Upper Esk were also sampled. The three sites on the South Esk River were located approximately 8, 16 and 45 km downstream from the main South Esk river (5^{th} order) sampling site shown in Figure 1. Data from animals caught at these additional locations were included in the platypus morphology analysis, but were not included in the analysis of platypus occurrence in different stream orders due to differing trapping effort.

Animal Occurrence

The occurrence of platypuses in each stream/stream reach site was assessed using a variety of trapping methods designed to capture individuals as they moved up or downstream, as well as indirect signs (i.e., platypus

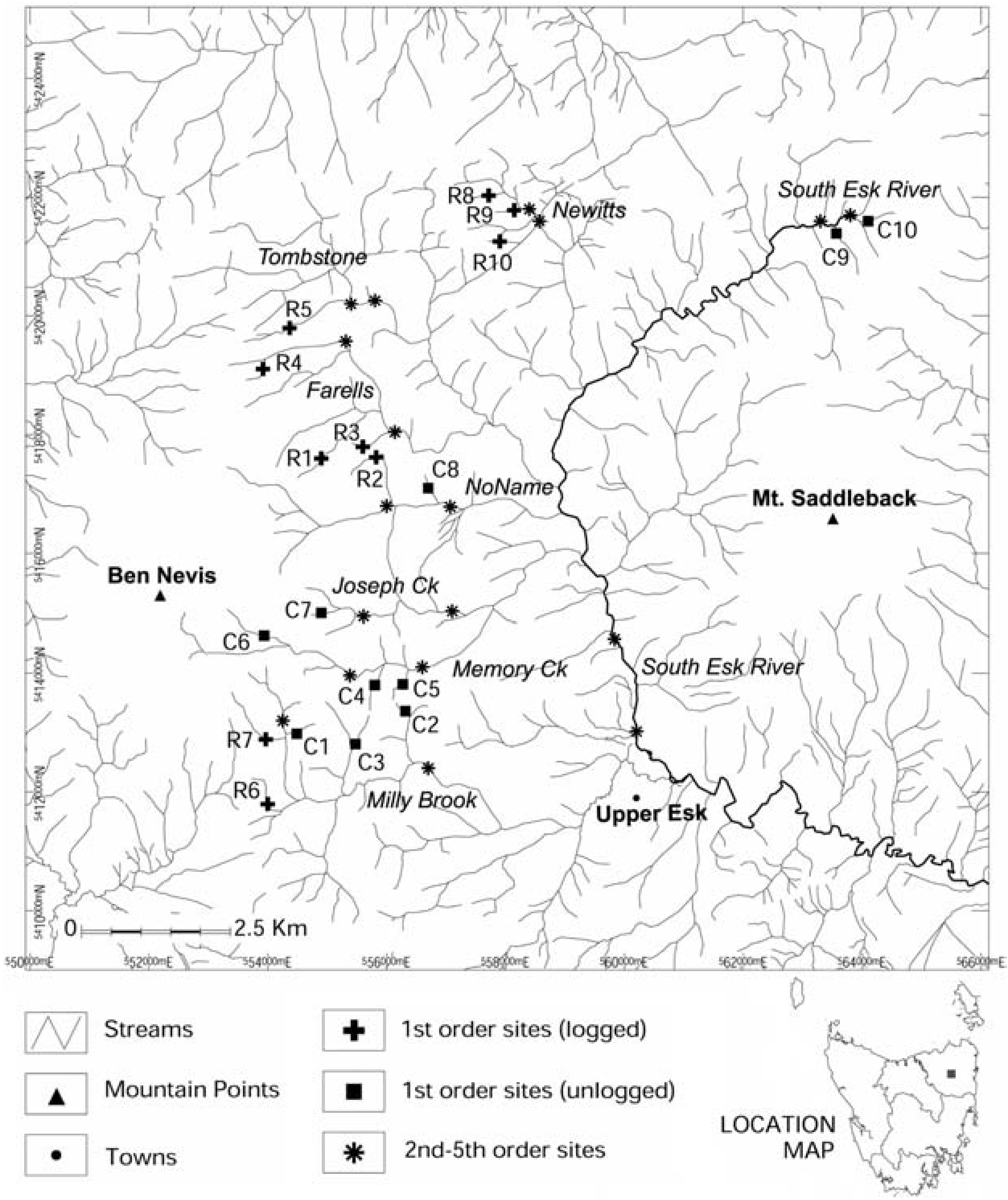

Figure 1. Location of the main sampling sites in the South Esk River upper catchment study area. For first order sites (logged and unlogged), the locations of upstream and downstream trapping sites have been combined.

tracks). For the latter, all areas of exposed mud along the first order streams were searched for platypus tracks and any locations of clearly identified platypus tracks (Triggs 1996) were recorded.

A three day preliminary trapping trip to establish methods was made in September 2000. Two four-day trapping trips were subsequently made between mid-Nov 2000 to April 2001 (one in late spring/early summer and one in late summer/early autumn).

Standard trapping methods (gill and fyke netting) were not suitable for the first order streams due to their small size. The water in these streams rarely exceeded 25 cm in depth and some were dry during late summer/early autumn, although swampy areas nearby maintained connectivity of platypus habitat. A modification of the standard treadle cage trapping method, for medium sized vertebrates, was used in all first order streams samples. Wire cage traps (560 mm long x 200 mm wide x 200 mm high, Mascot Wireworks Ltd) with plastic mesh wings

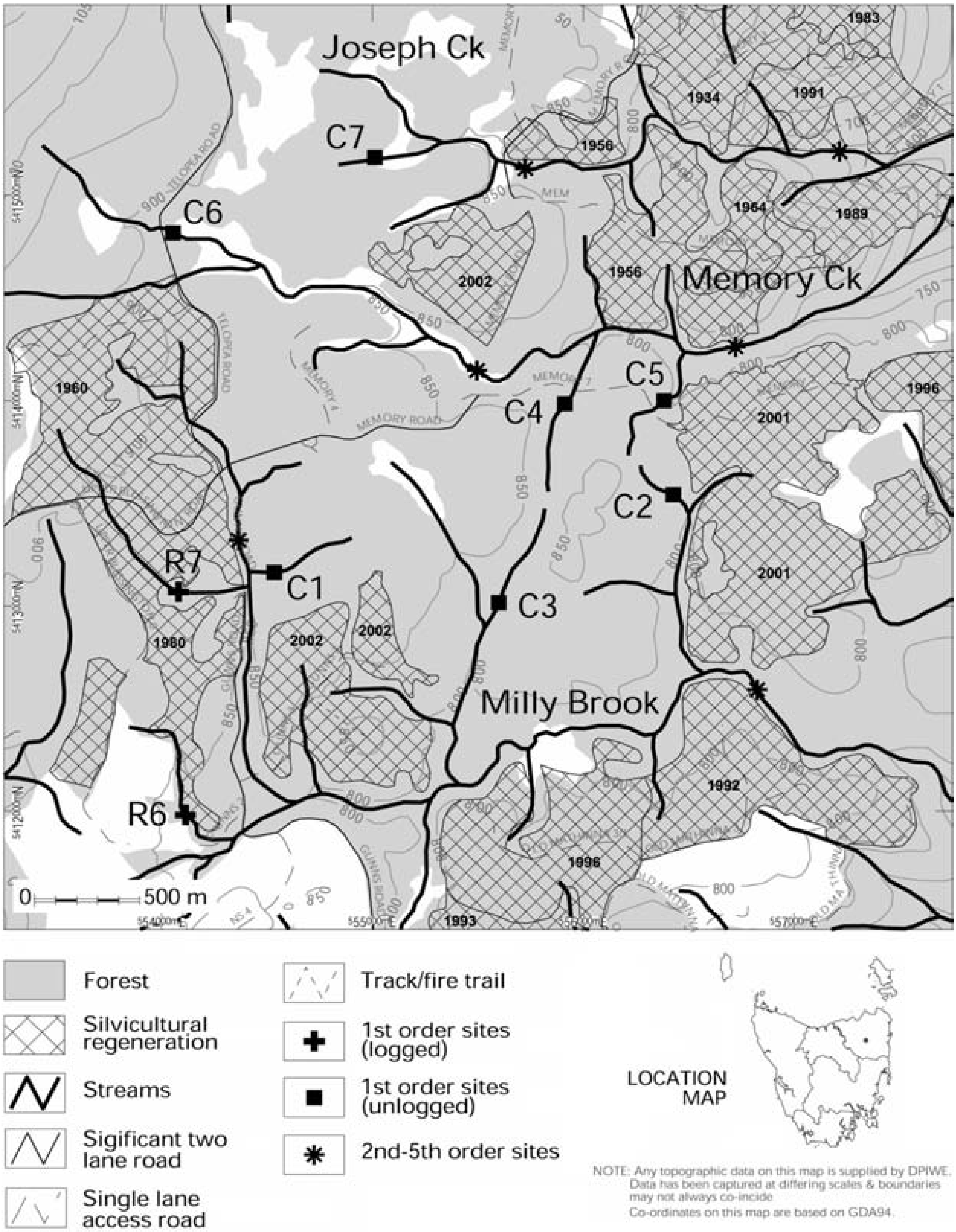

Figure 2. The extent of disturbance by forestry operations for logged sites R7 and R6. Control sites (Cn) are also illustrated.

(0.4 m high, 2m long), held upright by stakes, sealed with stones, and stretching to the stream bank to block the whole channel, were placed on the stream bed in shallow pools (max. depth of 5 cm), riffles or dry areas. Fyke nets were used (as in Serena 1994) for the main sampling sites in the second-fourth order streams and the fifth order river reach (Figure 1).

Two sub-sites, each with two cage traps (one facing upstream, one downstream) or two fyke nets (one facing upstream, one downstream) or two 'double fyke' nets (2 fykes connected in a line to span the river, one facing upstream, one downstream), were established per stream or river reach site. The mean distances between upstream and downstream trapping sub-sites in the first order and

second-fourth order streams were 246 m $\pm$ 98m (range = 100 – 450 m), and 1.28 km $\pm$ 682m (range = 700 – 2500 m), respectively. The distance between the upstream and downstream sub-sites for the fifth order river reach was 1.3 km. All the main sampling sites (Figure 1) were trapped in this way for four consecutive nights during the two four-day trapping trips. Traps were checked as often as logistically possible. Every effort was made to check gill nets at least every 10 minutes and to check Fyke nets and cage traps at least every half hour. The maximum amount of time between checking, for Fyke nets and cage traps, was two hours.

Trapping effort over the study period, was the same for all of the main sampling sites (Figure 1), with 176 net or trap hours per stream or river reach (one net or trap hour = two traps or nets, one facing upstream and one downstream, set for one hour). Traps/nets were set in the early afternoon between 1500 and 1900 hr and dismantled between 0000 and 0400 hr the following morning. Ensuring that the setting of traps and dismantling of traps, over the four day trapping period, started at a different location each day minimized any bias that may occur due to traps being set consistently earlier or later in a particular subset of the streams. A total of 3520 trap hours were spent in the first order streams, 1408 net hours in the second-fourth order streams and 176 net hours in the fifth-sixth order streams. Non-target species were caught in the cage traps on four separate occasions. These included two Australian water rats *Hydromys chrysogaster*, two longtailed mice *Pseudomys higginsi* (together in one cage trap) and one white footed dunnart *Sminthopsis leucopus*. The amount of trapping hours lost due to non-target species was considered negligible.

For the additional trapping sites (three farm dams and three additional reaches on South Esk River), unweighted or partially weighted 50 m gill nets were used (by the method of Grant and Carrick, 1978). The gill nets were placed to either span the river or farm dam in a zig-zag fashion, or parallel to the stream bank. A total of 125 net hours was spent at these sites.

All captured animals were marked with microchips (Trovan, Central Animal Records, Victoria), inserted subcutaneously between the scapulae (Grant and Whittington 1991). The body length of individuals was measured from the tip of the bill to the tip of the tail. Individuals were weighed using a spring balance (Salter, Australia) to within 20 g, and sexed and aged according to spur morphology (Temple-Smith 1973). Four age categories after first emergence from the nesting burrow were recognized for males based on changes in spur morphology: Stage 1 (< 6 month) and stage 2 (6 - 9 month) juveniles, stage 3 (9 - 12 month) subadults, and adults (> 12 months). Females were classified as juvenile (< 10 months) or subadult/adult (> 10 months). Body condition was assessed by means of a standard Tail-Fat Index (Grant and Carrick 1978). This index provides a qualitative estimate of an animal's stored fat and overall body condition. Animals were rated from one to five, where one represents individuals with high fat stores and five represents individuals with low fat stores. All individuals were released at the site of capture.

Habitat variables recorded for each first order stream site

Habitat variables recorded at each first order stream site were chosen for their likely importance in determining habitat quality for the platypus (some were modified from variables described in Grant and Bishop 1998).

The following broad environmental variables were recorded for each of the twenty, first order streams sampled in this study:

- Catchment area (m^2);
- Percentage of catchment vegetation regenerating after logging.
- Total length of the stream from its source to the intersection with the next stream (m);
- Length of stream with no surface flow (m);
- Slope of the stream (%);
- Length of the stream covered in dense log jams (m).

One to three 50 m representative reaches were selected per first order stream, ensuring that at least 10% of the total stream length was sampled. A set of local environmental or 'habitat' variables was then measured at all first order stream study sites. Each 50 m study reach was divided into four 12.5 m sections. Habitat variables measured for each of these 12.5 m sections or at 0, 12.5, 25, 37.5 and 50 m points along each 50 m reach are detailed in Table 1. It was not possible to record some of the variables along every first order 50 m reach. For example, the depth and width of water in pools was not recorded where pools were not present within the section.

All the variables recorded were considered to relate either indirectly or directly to the biology of the platypus (e.g. variables influencing benthic invertebrate production and diversity, burrowing requirements and movement).

Data analysis

Since all the streams where the main sampling sites were located (Figure 1), were subject to the same trapping effort (ie., 176 net/trap hours per stream), the catch success of platypuses for each of the three stream order groups (first, second-fourth and fifth order) was determined as:

Catch success = Total number of individuals caught in a stream group ÷ Total number of streams trapped for a stream group.

It should be noted that in the context of this particular study, catch success provides an index of relative usage but not population density.

The association between the captures of juvenile and sub-adult males and stream group was tested using chi-square test. The occurrence of platypuses in disturbed (historically logged) and relatively undisturbed first order streams was compared using the Mann-Whitney-U test. Levels of statistical significance were set at 0.05.

Table 1. Habitat variables recorded within each 50 m study reach of all first order streams sampled.

Variable	Description
Slope of the stream	Slope of stream channel (%). Measured for each 12.5 m section, and averaged over study reach.
Number of drainage channels	Estimated number of drainage channels within each 12.5 m section.
Runs and pools	Percentage of run and pool reaches for each 12.5 m section. Depth and width of water in pools and runs (cm). Height of pool bank (cm).
Bank Structure	Average width and length of undercut bank (m). Measured for each 12.5 m section.
Channel bed form	Form of channel bed, allocated to categories (1=V form, 2 = U form, 3 = flat). Assessed at 12.5m points along each 50 m reach.
Channel bed substrate	Estimation of percentage cover of organic material, sand, silt, gravel, stones, rocks and bedrock. Measured for each 12.5 m section.
Bank substrate	Presence or absence of rocks in the stream bank. Measured for each 12.5 m section.
Bank Stability Index	A measure, allocated to four categories, of bank stability (Class 1 = stable banks, no erosion, no exposed roots, to Class 4 = bank unstable, undercutting, erosion, no bank vegetation). Measured for each 12.5 m section.
Riparian zone slope	Slope in degrees of the valley sides within 20 m of stream bank. Assessed at 12.5 m points along each 50 m reach.
In-stream debris dams	Number of debris dams (collections of vegetation debris) along the 50 m reach. Counted in each 12.5 m section.
In-stream logs	Number of logs, allocated to two size classes (< 50 and > 50 cm diameter) lying in the stream channel. Counted in each 12.5 m section.
Suspended stream logs	Number of logs, allocated to two size classes (< 50 and > 50 cm diameter) lying over the stream channel, above the water level. Counted in each 12.5 m section.
Logs in riparian zone	Number of logs (> 80 cm diameter) in the riparian zone (within 20 m of the stream). Counted for each 12.5 m section.
Stream canopy density	Estimate of projected canopy density (%) over the stream. Assessed at 12.5 m points along each 50m reach.
Overhanging vegetation	Estimate of % cover of vegetation (< 2 m in height, ferns, small shrubs) overhanging the stream. Assessed for each 12.5 m section.
Vegetation cover in riparian zone	Percentage ground and understorey vegetation cover in riparian zone (within 20 m of the stream). Estimated for each 12.5 m section.
Moss cover at stream bank	Percentage moss cover (%) at stream edge. Estimated for each 12.5 m section.
Tree species in riparian zone	Number of tree species in the riparian zone (within 20 m of the stream). Estimated for each 12.5 m section.

The body mass and total length of platypuses were compared between stream order groups using one-way analysis of variance (ANOVA) followed by a Fisher LSD post-hoc test.

The relationship between the broad habitat variable measurements obtained for the first order streams with relatively undisturbed catchments and those obtained for the first order streams with catchments disturbed by logging was explored using the Spearman Rank Correlation. Similarly, the relationship between the broad habitat variables recorded for the first order streams where no platypuses were caught, those where one platypus was caught and those where two platypuses were caught was explored using the Spearman Rank Correlation. The 0.05 level of significance was accepted as indicating statistical significance.

Values for habitat variables measured for each 12.5 m section or point locality along the 50m reaches were averaged for each stream prior to further analysis. A Principal Components Analysis (PCA) was performed on the mean instream habitat variable data (Table 1) collected for the twenty, first order study streams in order to reduce the number of variables to a smaller number of components. These components were then used to evaluate differences between the first order streams disturbed by logging and the relatively undisturbed first order streams, by ANOVA. The relationship between the PCA factors found to best describe the effect of treatment on the instream habitat variables and the occurrence of platypuses in the first order streams was explored using Spearman Rank correlation (with statistical significance accepted at $p = 0.05$).

Logistic regression analysis (backward stepwise) was also used to explore the relationship between the presence/absence of platypuses (as the dependent variable) and environmental variables (as independent variables). Model suitability was assessed by examining the 95% bounds of parameter odds ratios, a Chi-squared test based on log likelihood, and McFadden's rho-squared (Wilkinson 2000; Quinn and Keough 2002). Relative model performance was assessed using the G statistic based on differences between model log likelihood ratios, assessed as a Chi-square statistic.

The 0.05 level of significance was accepted as indicating statistical significance. All analyses were conducted using the SYSTAT software package (version 10.0).

Results

Occurrence of platypuses

A total of 78 individual platypuses were caught in the study area (all main sampling sites and additional trapping sites). Fifty four individuals were caught during the main trapping program at the main sampling sites (Figure 1, Table 2). Twenty-two individuals were caught during the preliminary trapping undertaken in September 2000 (second-fourth order streams) and the incidental trapping of the three additional South Esk river sites (fifth or sixth order reaches) and three farm dams. Two juveniles were caught by hand at the edge of a farm dam. Six of the 78 individuals were caught during the daylight hours including the two juveniles caught by hand.

Platypuses were trapped at all of the main sampling sites in the second-fourth order streams and the fifth order river reach (Figure 1). They were also trapped in nine of the 20 first order streams. Catch success, calculated for the main sampling sites, was highest in the fifth order river reach (9.0) compared with the second-fourth order and first order stream groups (4.5 and 0.6, respectively).

Thirty-five of the 78 individuals caught in the study area (at all main sampling sites and additional trapping sites) were females and forty-three were males (Table 2). The proportion of platypuses (adults and subadults) that were females, caught in the first order, second-fourth order, and fifth-sixth order streams and dams was 0.44, 0.4 and 0.57, respectively.

Six of the males caught in the study area (at all main sampling sites and additional trapping sites) were juvenile (estimated to be 6-9 months old from spur morphology) and two were sub-adult (9-12 months) (Table 2). There was a trend towards a higher proportion of juveniles and of sub-adult males in the smaller headwater streams (Table 2). However, there was no statistically significant association between the captures of juvenile and subadult males, and stream group ($X^2_1 = 2.12$, $P>0.05$).

In general, a higher proportion of individuals were caught during the summer (November/January) than in autumn (March/April) (Table 2). For the main sampling sites, 89% of individuals in the fifth order river reach and 72% of individuals in the second to fourth order streams were caught during the summer trapping period. In contrast, only 44% of the animals caught in the first order streams were caught in summer.

Nine platypuses were trapped in 6 of the 10 first order streams whose catchments were relatively undisturbed (Table 3). Fresh platypus tracks, consisting of clear footprints and dragged tail prints, were also observed in a seventh stream in this group. Despite the same amount of trapping effort (176 trap hours per first order stream), only three platypuses were trapped in the 10 disturbed streams, from three streams, and no indirect signs were observed (Table 3). This difference in the occurrence of

Table 2 Captures of platypuses at all main sampling sites and additional sites in the upper South Esk River catchment between September to April 2001.

Captures	Occurrence of Platypus in Stream Groups					
	Fifth order		Second-fourth order		First order (disturbed)	First order (undisturbed)
	Main sites	Additional sites (dams and fifth/sixth order)	Main sites	Preliminary Sept trapping		
Number of individual females (adult/subadult) caught per stream group	4	12	14*[1]	1	3	1
Number of individual adult males caught per stream group	5	6	20*[2]	1	0	5*[3]
Number of individual subadult males caught per stream group	0	1	0	1	0	0
Number of individual juvenile males caught per stream group	0	1*[4]	2	0	0	3
Number of individual juvenile females caught per stream group	0	1*[4]	0	0	0	0
Total number of individuals caught per stream group	9	21	36	3	3	9
Total number of recaptures within a stream group	4	16	6	0	0	0
Total number of captures per stream group	13	37	42	3	3	9
% of individuals caught during Spring/Summer trapping at main sites	89%	-	72%	-	0%	44%

*[1] Includes one female first caught in disturbed first order stream group.
*[2] Includes one adult male first caught in undisturbed first order stream group.
*[3] Includes one adult male first caught in second-fourth order stream group.
*[4] Caught by hand at edge of farm dam.

Table 3. Occurrence of platypuses (from captures or indirect signs) in first order streams and undisturbed and disturbed by clearfell forestry operations in 1985. Location of streams are illustrated in Figures 1 and 2.

Undisturbed streams	Number of individual platypus	Disturbed streams	Number of individual platypus
C1	0	R1	0
C2	1	R2	1
C3	1*	R3	0
C4	2	R4	0
C5	1	R5	0
C6	2	R6	0
C7	1	R7	0
C8	0	R8	1
C9	0	R9	1
C10	2	R10	0

* from fresh platypus tracks observed in this stream.

platypuses, however, was only significant ($Z = -2.032$, $p = 0.042$) when it was assumed that the observation of fresh platypus tracks in one of the undisturbed streams was equivalent to a trapping observation.

Body length, mass and condition

The body length of both males and female adult platypuses caught in the study area varied significantly according to stream order ($F_{(2,32)} = 13.494$, $p < 0.001$; $F_{(2,31)} = 10.074$, $p < 0.001$, respectively). Males and females caught in the South Esk River (fifth and sixth order river reaches) and dams were the longest (538 ± 33 mm, n = 11; and 459 ±17 mm, n = 16, respectively). Males and females caught in the first order streams were the smallest (459 ± 25 mm, n = 4; and 418 ± 41 mm, n = 4, respectively). The mean body length of adults caught in the second-fourth order streams was 500 ± 24.97 mm (n = 20) for males, and 424.28 ± 24.4 mm (n = 14) for females.

The mean body mass of adult males and adult females also varied significantly according to stream order ($F_{(2,32)} = 19.50$, $p < 0.001$; $F_{(2,31)} = 18.607$, $p < 0.001$, respectively). The mean body mass of adult males and females was highest in the South Esk River (fifth-sixth order river reaches) and adjacent dams (2024 ± 264 g, n = 11; and 1251 ± 120 g, n = 16, respectively) and lowest in first order streams (1475 ± 191 g, n = 4; and 915 ± 122 g, n = 4, respectively). The mean body mass of adults caught in the second-fourth order streams was 1613.5 ± 146 g (n = 20) for males, and 1030 ± 125 g (n = 14) for females.

The range of tail fat index values recorded also differed between stream order groups. Tail fat index for the adult males and females caught in first order streams ranged from 1.5 to 3 (mean and sd = 2.1 ± 0.6, n = 4) and 2 to 3.5 (2.5 ± 0.7, n = 4), respectively. The tail fat index of adult males and females caught lower in the catchment (fifth/sixth order river reaches) ranged from 1 to 2 (1.5 ± 0.5, n = 11) and 1 to 3 (1.8 ± 0.6, n = 16), respectively. The tail fat index of adult males and females caught in the second-fourth order streams ranged from 1 to 3.5 (mean 2.1) in both sexes (males: sd = 0.8, n = 20; females: sd = 0.6, n = 14).

Relationship between the occurrence of platypuses in first order streams and habitat variables

The total length of the stream covered in dense log jams was significantly correlated with the presence of platypus (Table 4). No other correlation with 'general' environmental variables was statistically significant.

Principal components analysis (PCA) conducted on the mean habitat variable values derived for the first order streams resulted in a first component (Factor 1) which accounted for 24% of the variance in the data. Factor 1 was positively correlated with the bank stability index, number of logs (> 50 cm diameter) overlying the channel water, number of in-channel logs (> 50 cm diameter), proportion of sand in the streambed (%), slope of the

Table 4. Relationship between general stream variables, stream disturbance and the occurrence of platypus (Spearman Rank correlation coefficients). p = significance level; NS = non significant., S = significant (p < 0.05), HS = highly significant (p < 0.01).

	Disturbance			Platypus occurrence			
	Correlation coefficient	p	Sig.	Correlation coefficient	p	Sig.	N
Total length of stream (m)	0.321	0.167	NS	-0.131	0.582	NS	20
Overall slope of stream (%)	0.269	0.251	NS	-0.190	0.423	NS	20
Catchment size (m^2)	0.000	1.000	NS	0.091	0.704	NS	20
Percentage of catchment vegetation regenerating after logging	0.927	0.000	HS	-0.365	0.114	NS	20
Total length of dense log jams along stream (m)	0.583	0.007	HS	-0.478	0.033	S	20

riparian zone (%), number of tree species in the riparian zone, % stream reach as run, slope of the stream (%) and number of logs in the riparian zone (all $p < 0.05$ by Pearson correlation, $n = 20$). PCA Factor 1 was also negatively correlated with the proportion of organic material in the stream channel (%), the number of additional drainage lines and the bankfull depth of pools (cm).

The magnitude of PCA Factor 1 was significantly higher in the disturbed (historically logged) than in the relatively undisturbed first order streams, by one-way ANOVA ($F = 6.57$, $p = 0.02$). The remaining PCA components (Factors 2 and above) were not significantly different between the two logging treatment stream groups.

In general, the disturbed first order streams were more incised, had lower bank stability, less organic material in the stream channel, higher frequency and size of debris dams (indicated by more large logs both in-stream and in the riparian zone), more length of narrower runs, and shallower pools than the relatively undisturbed streams (Figures 3a, c and e).

The number of platypuses caught in the first order streams was significantly correlated with PCA Factor 1 ($r = -0.718$, $p < 0.001$, $n = 20$). Platypus numbers were positively correlated with the proportion of organic material in the stream channel (%) (Figure 3b). Platypus numbers were negatively correlated with the bank

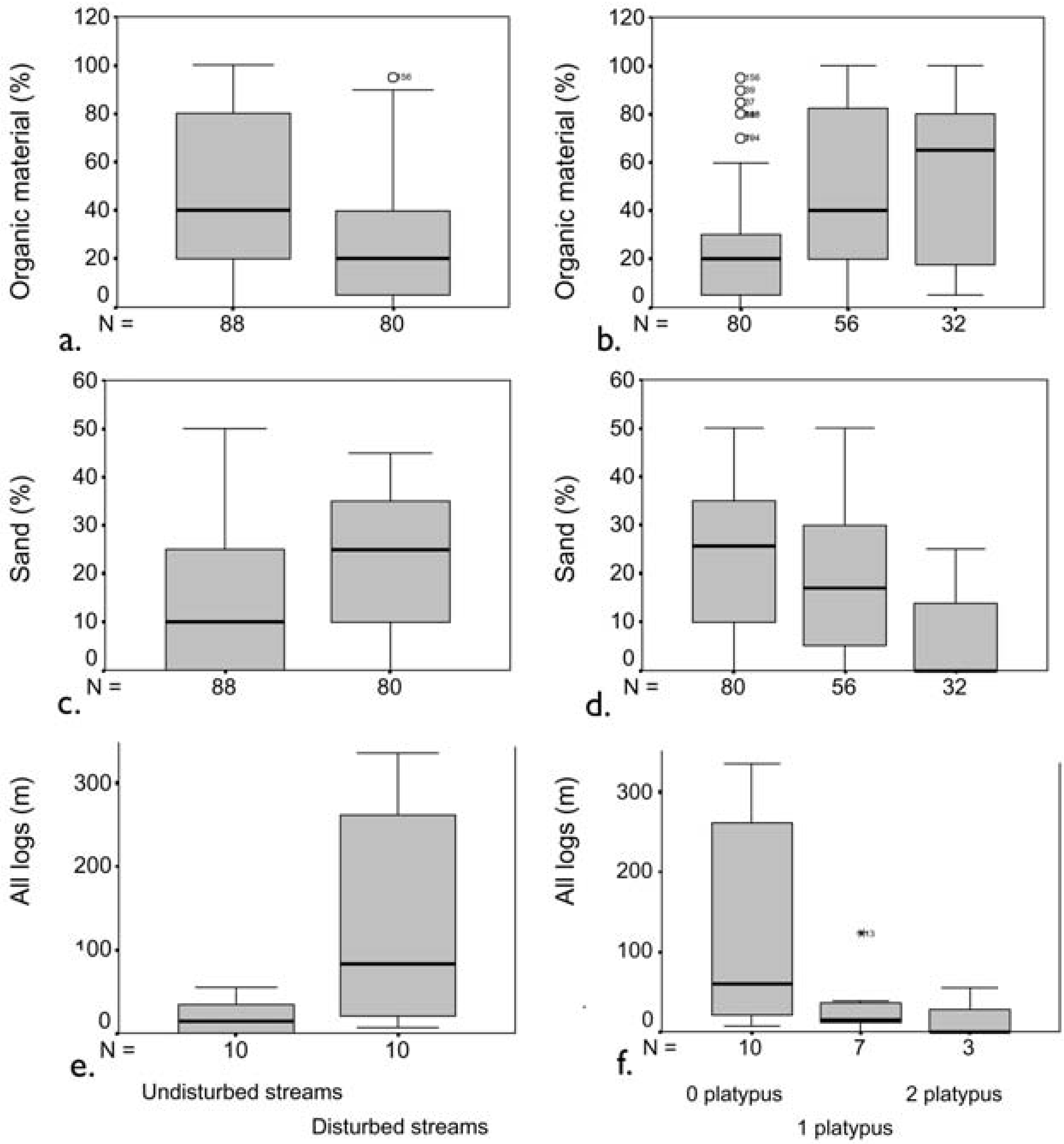

Figure 3. Variation in three key habitat variables, between disturbed and undisturbed first order streams and with occurrence of platypuses in first order streams. Box plots indicating medians (bold lines), interquartile ranges (boxes) and outliers (whiskers and points) for all measurements made at all sections in each stream (number of measurements indicated by N).

stability index, number of logs (> 50 cm) over water, number of logs (>50cm) in water and the proportion of sand in the streambed (%) (Figures 3d and f).

The logistic regression model that best described the occurrence of platypus in a first order stream had a statistically significant log-likelihood ratio (Chi-sq, p = 0.001) based on only two variables – the proportion of organic material in the stream channel (%) and the bank stability index (Table 5). There was an increased probability of presence of platypuses with increasing proportion of organic material in the stream channel and increasing bank stability.

In general, streams where no platypuses were caught were more incised, had less organic material and more sand (Figures 3b,d), less stable banks and more log barriers, than streams in which one or more platypuses were caught (Figure 3f).

Discussion

Platypuses are known to utilise small streams in the headwaters of river catchments in Tasmania, with locality records from streams up to 1200 m above sea level (Rounsevell *et al.* 1991; Connolley and Obendorf 1998; Otley 2001). This study confirmed the use of first order, semi-ephemeral headwater streams by platypuses in the South Esk River catchment. Individuals were caught in all types of watercourse surveyed, from the first order streams at the top of the South Esk catchment (altitude 900 m) to the larger fifth order river reaches and farm dams in the lowland area (Figure 1). Catchment size, creek length and the amount of dry riverbed were not important predictors of platypus occurrence in the first order streams in this study. Although some of the first order streams were occasionally dry during the study, adjacent wet swampy areas connected them. Other studies have recorded platypuses in the headwaters of river catchments on mainland Australia (Grant *et al.* 2000) and they are known to persist in water bodies during no-flow periods (Souter and Williams 2001).

The frequency of platypus occurrence in the first order streams, based on catch success and assuming that the trapping methods used were equally effective was lower than in the larger streams and river reaches (second – fifth order). Since the mean distance between paired netting sites was roughly five times shorter in the case of first order streams than in higher order streams, the catch success in first order streams relative to higher order streams is likely to be even lower than indicated by the results. This is not surprising since the larger streams and river reach in the South Esk River had better habitat. Although the riparian and aquatic habitat in headwater areas may be more marginal for platypus, it is extensive - in the South Esk catchment, first order streams form 51% of the total length of watercourses (Table 6). This indicates that habitat available in headwater areas may be important for the maintenance of a significant component of the overall platypus population in the South Esk River catchment. This may apply in other catchments, particularly where platypus habitat in the lowland streams and rivers has been altered or lost through agricultural clearing, or other anthropogenic activity.

Table 6. Total stream length of streams of different orders in the South Esk River catchment (from Digital Elevation Model, Forestry Tasmania, unpublished data, 2001).

Stream Order	Stream length (km)
1	1225
2 - 4	1067
5	55
6	37
Total	2384

Platypuses in Tasmania appear to be generally larger than on the mainland (Connolly and Obendorf 1998; Bethge 2002). However, as observed for platypuses captured in various water bodies in New South Wales (Grant and Temple-Smith 1983), there also appears to be differences in body mass between populations in different water bodies in Tasmania (Table 7). Individuals caught in the first order streams of the South Esk catchment were generally smaller and possibly in poorer condition, as indicated by their tail fat index, than individuals caught in the larger streams and river. Handasyde *et al.* (1992) also reported lighter individuals from small streams compared to individuals caught in lakes or larger streams. However, this difference may also be explained by between catchment variation, as in their study samples from small streams were obtained from the Yarra River catchment and those from large streams were obtained from the Goulburn River catchment.

The results from this study indicated a higher proportion of males and sub-adults and juveniles in the smaller headwater streams. Nestlings are known to emerge from their natal burrows in the South Esk River and associated tributaries at Upper Esk in the autumn months (field observations from this study and Munks *et al.* unpublished data), hence the higher proportion of captures in the first order streams in the autumn months may correspond with the dispersal of sub-adults as juveniles enter the population in the lowland habitats. From these results it is tempting to postulate

Table 5. Summary of the logistic regression results for the relationship between platypus presence/absence and first order stream habitat variables.

Parameter	Estimate	S.E.	t-ratio	p-value
Constant	3.655	3.738	0.978	0.328
Stream channel organic material (%)	0.089	0.048	1.855	0.064
Bank stability class	-2.514	1.465	-1.716	0.086

Table 7. Mean body mass of adult platypuses caught in various water bodies in Tasmania and mainland populations.

Populations	Mean body mass of adult females (kg) (n)	Mean body mass of adult males (kg) (n)	Sources
Mainland			
Shoalhaven River, NSW	0.84 (279)	1.37(132)	Grant and Temple-Smith (1983)
Childowla, NSW	1.23 (56)	1.76 (34)	Grant and Temple-Smith (1983)
Thredbo River, NSW	0.78 (21)	1.24 (34)	Goldney (1995)
Watts River and Badger Creek, NSW	0.96 (9)	1.55 (12)	Gardner and Serena (1995)
Overall mean ± sd	0.95 ± 0.20 (n=4)	1.48 ± 0.23 (n=4)	
Tasmania			
South Esk River - Order 1	0.91 (4)	1.47 (4)	This study
South Esk River - Order 2-4	1.03 (14)	1.61 (20)	This study
South Esk River - Order 5/6 and dams	1.25 (16)	2.02 (11)	This study
Mersey River	1.22 (5)	1.90 (2)	Connolly and Obendorf (1998)
Salmon Ponds	1.24 (7)	1.85(12)	Bethge (2002)
Lake Lea	1.47 (15)	2.10 (30)	Bethge (2002)
Brumbys Creek	1.49 (12)	2.50 (22)	Connolly and Obendorf (1998)
Overall mean ± sd	1.23 ± 0.21 (n=7)	1.92 ± 0.33 (n=7)	

that although the habitat in the headwater streams may be marginal it is important for dispersing subadults. Alternatively, as speculated by Grant (1995) for small ephemeral upland streams on Kangaroo Island, the headwater streams may be marginal habitat areas used by varying number of animals depending on rainfall conditions providing enough foraging area.

Impacts of habitat disturbance in first order streams.

The results of this study indicate that platypuses inhabiting the headwaters of the South Esk catchment may prefer relatively undisturbed streams to those disturbed in the past by logging practices due to a reduction in habitat quality. Key elements of 'ideal' platypus habitat, summarised by Grant and Temple-Smith (1998), were observed in the relatively undisturbed first order streams: banks consolidated by the roots of native plant species with overhanging foliage, a diversity of 'in-stream' habitats, including aquatic vegetation, 'in-stream' logs, and a series of distinct shallow pools, with little sand accumulation, and separated by cobbled riffle areas. Many of these habitat features were lost or reduced in the streams that had been disturbed in the past by the clearfelling, burn and sow practice. The differences in 'in-stream' habitat between the logged and unlogged streams, observed in this study, were also noted in a concurrent study that examined the geomorphology and sedimentology of 10 of the first order streams we sampled (Bunce *et al.* 2001, Davies *et al.* 2005 a). As well as 'in-stream' differences, there were differences in the riparian areas of the disturbed streams compared with the relatively undisturbed streams, including lower bank stability, overall lower density of the vegetation canopy, reduced vegetation ground cover and reduced overhanging vegetation (Davies *et al.* 2005a). Overhanging vegetation has been shown to be important for the hiding of burrow entrances (Serena *et al.* 1998). It seems reasonable to assume that some of these 'riparian' differences, coupled with the 'in-stream' differences, would be associated with changes in in-stream food availability for the platypus and Davies *et al.* (2005b) found an overall reduction in macroinvertebrate biomass in the logged streams. Serena *et al.* (2001), however, suggested that platypus may select optimal foraging areas based not only on prey availability, but also on the amount of time and effort required to detect, capture and consume food items. The presence of more overlying logs and instream log jams and exposed boulders (this study and Davies *et al.* 2005a) and the reduction in fine silt backwater habitats and sediments more suitable for platypus feeding are factors considered most likely to have resulted in the trend toward a lower occurrence of platypuses in disturbed streams in this study.

Since a retrospective approach was taken in this study it could be argued that processes other than the past forestry operations have resulted in the differences observed in platypus occurrence and stream character in the first order streams. Ideally, a BACI-type designed study (Underwood 1997) needs to be undertaken in another upper catchment area to further elucidate effects of forestry activities on platypus and their habitats. However, as discussed in Davies *et al.* (2005 a) and Bunce *et al.* (2001), every effort was made to choose catchments that were similar before the forestry operations began, in terms of drainage character, stream slope, vegetation, soil, geology and rainfall. The differences in the characteristics of the streams and the use of the streams by platypuses are therefore considered to be predominantly due to the direct and indirect effects of the historical clearfell, burn and sow operation (Bunce *et al.,* 2001) which have caused long-term changes in vegetation and stream features. Obvious effects include the large increase in logs both in and around the disturbed streams. Factors such as lower bank stability could be attributed to increased erosion resulting from increased stream flow rates in the clearfelled catchments after harvest (Vertessey1999).

Conservation considerations

The platypus is currently considered common throughout its range and is known to occur in modified habitats, including streams flowing through urban and agricultural areas (Grant 1991; Grant 1998; Serena and Williams 1998; Serena *et al.* 1998). Although reliable data are not

available, it is likely that the platypus was more abundant before European colonization and that commercial hunting for pelts, followed by the continuing and increasing disturbance of habitat caused by poor land management practices, have resulted in local population declines (Grant and Temple-Smith 1998, 2003). In Tasmania, platypuses are listed as Protected Wildlife under the Tasmanian Nature Conservation Act 2002. This Act protects both the platypus and its products, including known burrow sites. Under the Act a person must not 'take' damage or destroy a platypus or its burrow unless authorized by a permit. The permit issued by the relevant government agency responsible for administering the Act may apply conditions to the permit that aim to mitigate impacts on the species while allowing land use activities.

The degree of impact of habitat disturbance, including forestry activities, on platypus populations is likely to vary according to the part of a drainage system that is affected and the time of year. It is generally accepted that disturbance to optimal habitat in lowland rivers and streams can impact on breeding individuals. This study suggests that extensive disturbance to headwater areas could also potentially impact on platypus populations within a particular catchment.

The clearfell, burn and sow operations in the catchments of the disturbed first order streams sampled in this study occurred prior to the development of the Tasmanian Forest Practices Code (Forest Practices Board 2000). Hence the operation included crossings of streams by heavy machinery, dragging of trees along and across first order streams, and felling of trees into streams (clearly observed from aerial photographs taken immediately post-harvest and post-burn, Davies *et al.* 2005a, and confirmed by discussions with harvesting personnel), activities no longer permitted under the Code. The results of this study suggest that the direct and indirect effects of such harvest activities may reduce the quality of habitat for the platypus for up to 15 years.

The current Code provisions, developed in 1993, and reviewed and refined in 2000, aim to reduce the direct effects of clearfell, burn and sow operations on streams. The provisions, however, do little to reduce the indirect effects of increased streamflow after harvest (Bunce et al. 2001). Consideration should be given to the development of further management actions that aim to retain sufficient riparian reserves and/or disperse logging impacts, such that an adequate number of streams are allowed to regenerate and/or recover from post-harvest hydrological disturbance. This may also enable platypuses to recolonise an area before additional headwater streams and associated riparian areas are disturbed (platypuses are known to utilise habitat up to 20 - 30 m away from the stream edge for burrowing (Otley *et al.* 2001; Munks *et al.* unpublished data). This is particularly important in catchments where platypus habitat is already degraded through other land use activities, and/or where platypus populations are subject to disease, or mortality rates are high due to other known causes (Connolly *et al.*, 1998; Munday *et al.* 1998).

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APPENDIX I

Cage trap with plastic mesh wings in first order stream.

Photo: N. Koch and M. Utesch.

Fyke net in a second-fourth order stream reach.

Photo: N. Koch and M. Utesch.

APPENDIX I

Filming a platypus in the farm dam.

Photo: N. Koch.

The senior author and Upper Esk platypus during the night shift.

Photo: M. Utesch.

A first order stream and result of logging disturbance.

Photo: N. Koch and M. Utesch.

APPENDIX I

A relatively undisturbed first order stream in the South Esk River catchment.

Photo: N. Koch and M. Utesch.